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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

The Research Phase of
Sulfurized Cutting Oils

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TEXACO

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TEXACO CUTTING, SOLUBLE AND HYDRAULIC OILS FOR FASTER MACHINING

LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

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The Research Phase of Sulfurized Cutting Oils

THE PETROLEUM INDUSTRY has manufactured and marketed cutting oils ever since Taylor* in the late nineties had the courage to predict the importance of the cutting fluid as an adjunct to surface finish in metal cutting. This research played an important part in later machine tool developments. During the period which followed, up until the late twenties the need primarily was for the conventional types of mineral-lard oil mixtures. For the type of pipe-threading and metal cutting which then prevailed they were moderately satisfactory. As cutting tool speeds increased and alloy steels became more common however, an oil of better cutting ability was required. It was found that when a mineral-lard oil is overworked, it may break down chemically, then it becomes rancid, develops an objectionable odor and often is quite harmful to the skin.

This prompted renewed study of the problems of metal cutting. Leading members of the Petroleum Industry had anticipated this trend and had been studying cutting oil components for some time previously and had developed experimental cutting oils containing sulfur. This element, when added correctly to mineral oils or mineral-lard oil, increases the cooling and lubricating ability and helps to prevent welding of the chip to the tool. Sulfurized cutting oils also have the ability to penetrate more readily to small crevices. This ability, along with added film strength, was found to give better surface finishes on steels which are difficult to machine.

FUNDAMENTAL research has been responsible for virtually every advance in petroleum technology since the Drake Well came in. As machine design progressed, the petroleum research worker kept pace. The modern Diesel, the aircraft engine, the high speed machine tool are but a few examples of progress which would have failed but for the contributions of the Petroleum Industry in the form of ever improved fuels and lubricants.

But machine design required another contribution – cutting fluids to make possible the improved surface finishes, the finer tolerances necessary for higher speeds and greater dependability. Petroleum base cutting oils made all this possible.

*F. W. Taylor, 1856-1915 — Mem. A.S.M.E.

THE STORY OF SULFUR

The use of sulfur as a component of cutting oils dates back to about 1888. Free sulfur had been added to mineral lubricating oils for some time previous, but the potential benefits in cutting oils remained obscure until research study was directed to perfecting better methods of mixing. These were indicated by the use of "sulfochlorinated" compounds. Any excess sulfur chloride or any hydrochloric acid which formed when fats were treated with sulfur chloride, could be neutralized by a suitable alkali or certain terpenes or olefins, thus insuring a product which would not be reactive.

From that period until about 1918, there was a lull. Then, with interest aroused perhaps by World War I, and the demand for munitions, the so-called second stage in the history of cutting oil research developed, and sulfur base oils became more seriously considered.

It has been known for years that the amount of sulfur which can be dissolved or combined with mineral oil is limited. The problem of how to extend the limits aroused the interest of a number of post-war investigators who studied the effect of elevated temperature as a means of promoting the reaction between the sulfur and hydrocarbon molecules.

The extension of this research prompted the widespread interest which can conveniently be regarded as the third stage. Increase in machine tool speeds, in cutting tool loads, in toughness of metals and the necessity for greater precision all contributed to the arrousing interest.

When more dependable cutting oils were required, more dependable methods of making them had to be developed. All this work considered sulfur as a fundamental component and assistant to effectual cutting tool cooling.

The Reason for Sulfurizing

Sulfurized cutting oils are not a cure-all for metal-cutting difficulties. In fact, certain conditions and some metals prohibit their usage. For example, highly sulfurized oils are not suitable for machining brass or non-ferrous alloys due to the active nature of the sulfur which causes the surfaces of these metals to turn black.

In other words, the nature of the cut and the type of metal are the dominating factors. Briefly, the addition of sulfur to a mineral oil enables better heat transfer, more rapid cutting and smoother surface finish on steel.

The Value of Transparency

In turn, whether or not a cutting oil should be transparent depends upon the advantages pertaining to being able to observe the cutting process as the work is turned against the edge of the cutting tool. Draining of the oil from the tool is an important item in connection with visibility. Consequently, the effects of reduced viscosity upon cutting ability were investigated. Oils of this nature are especially adapted to machining of low, medium and high carbon steels as well as the several types of alloy steels so necessary in the design of precision and heavy-duty machinery.

Reducing the Corrosive Tendency

Subsequent research in connection with sulfurized oils indicated that there was probably some relationship between the corrosive tendency and the way in which the sulfur is dispersed in the oil. It was noted that the corrosive nature of a sulfur cutting oil could be reduced by heating the oil sufficiently to cause the free sulfur to react with the mineral oil to form products which are non-corroding.

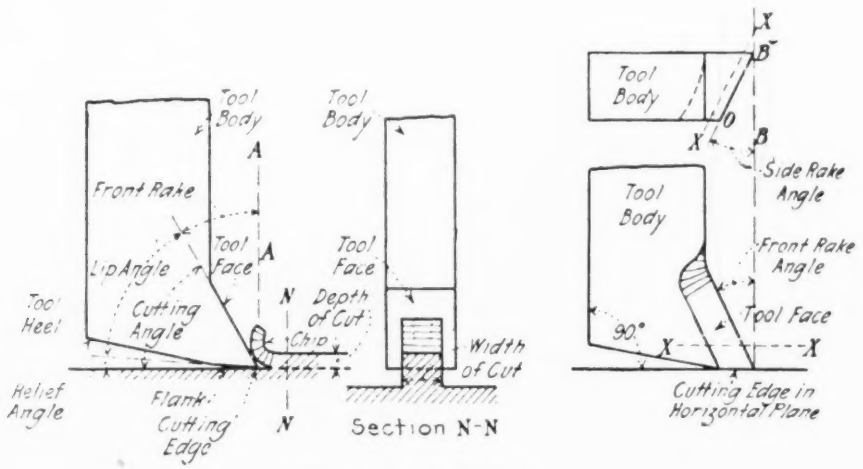


Fig. 1—Tool Parts and Angles

DEFINITION OF METAL CUTTING TERMS*

To fully understand the art of metal cutting requires knowledge of at least some of the more commonly used terms which are applied to the adjustment and shape of the cutting tool, etc. Likewise, familiarity with the more usual S.A.E. steel classifications is helpful in visualizing the type of steel being cut.

Relief Angle:

Relief Angle is the angle of the flank below the cutting edge to clear the work. It was formerly known as *clearance angle*. This is now an American Standard.

Rake Angle:

Rake Angle is the slope of the top face of the tool from the cutting edge. Back rake means toward the shank; it is the slope toward the center of the cutter. On a shank type tool it is measured from the cutting edge toward the shank (back rake) or from the cutting edge to the side at right angles to the shank (side rake).

*From Metals Handbook, 1939 Edition (pp. 892-896) "Machinability of Steel" and other notes, by O. W. Boston.

Built-up Edge:

Almost immediately after starting a cut, a small particle of the material being cut is trapped on the face of the tool and forms what is known as a *built-up edge*. The built-up edge is somewhat triangular in shape, being thickest directly ahead of the cutting edge, becoming thinner as it extends backward over the face of the tool.

Surface Finish:

The finish on the cut surface is improved as the built-up edge is reduced in size. This reduction may be accomplished by increasing the rake of the tool, increasing the speed, reducing the size of the cut, or introducing a cutting fluid, any one, or a combination of which is commonly used to secure better finish.

Tool Wear:

When cutting steel with tools of carbon tool steel, tool failure is usually caused by wear on the flank of the tool directly beneath the active cutting edge. When cutting steel with tools of high speed steel, normal tool failure is caused by a gradual cupping of the tool on its face. After the chip is formed, it slides over the built-up edge protecting the cutting edge, and rubs against the face of the tool some distance back from the cutting edge.

CUTTING SPEEDS AND FEEDS IN TURNING

When steels are machined in turret lathes with tools of high speed steel properly ground for roughing cuts from 1/16 to 3/16 in. in depth and feeds from 0.020-0.060 in., the cutting speeds that give satisfactory commercial values of tool life, according to Warner and Swasey Co. are:

Steel	*Surface Ft. per min.*
Alloy, Annealed	50—60
treated	25—40
Castings, miscellaneous	50—60
Machine, hard	35—60
medium hard	60—85
soft	100—120
Threading	25—40
Tool, annealed	60—80
unannealed	25—35

TABLE I. Speeds and Feeds with Rake and Relief Angles Recommended for High-Speed Steel Milling Cutters of the Production Type over 3 in. dia.*

Metals	*Cutting Speed F.P.M.*	*Feed In.p.m.*	*Angles in Degs.*	
			Rake	*Relief*
Aluminum	500-1000	10-24	20-40	10-12
Bakelite	100-200	8-10	5-10	5-7
Brass	100-200	10-24	0-10	10-12
Bronze	30-200	10-24	0-10	4-10
Cast Iron	50-120	24	8-10	4-7
Cast iron, malleable	80-100	10-24	10	5-7
Copper	100-200	10-24	10-15	8-12
Monel metal	70-80	4-6	10	5-8
Steel, alloy, heat-treated	30-50	4-6	10-15	4-5
Steel, alloy, not heat-treated Steel, annealed high-carbon	60-70	7-8	10-15	5-6
Steel, low-carbon, cold-finished	80-100	10-24	10-20	5-7
Steel, stainless	60-90	4-6	10	5-8

A cutting fluid should be used whenever possible. Carbon-steel tools should operate at speeds from 1/3 to 1/2 of those of high-speed-steel tools. The relief angles should be increased 25 to 50 per cent for cutters less than 3 in. dia.

*Metal Processing. O. W. Boston. p. 174.

HOW THE TYPE OF METAL AFFECTS POWER CONSUMPTION, TOOL LIFE AND CUTTING SPEED**

The metal removed by a drill, planing tool or milling machine cutter varies with the process for each metal. The power in drilling is usually higher than that of turning or planing because of the friction occurring between the chips and the flutes of the drill as they are removed from the hole, and because of the action of the chisel edge of the drill. In milling the average power consumption is higher because of the removal of the chips with very small average thickness. The chart shown as Fig. 2 is of interest in this regard.

In many operations long stringy chips are objectionable as they tend to mar the work surface, cause congestion of the machine parts and are difficult to remove.

Hardness of Steel

The hardness of steel reduces the cutting speed for a given tool life almost directly as the hardness is increased as shown in Fig. 3. Thus the cutting speed for a 50-minute tool life of mill annealed 4340 steel, when being machined with a feed of 0.0127" and depth of cut of 0.050", is about 136 fpm. For the same steel hardened to give a Brinell hardness of 492, the cutting speed for a 50-minute tool life is only 28 fpm. The Brinell hardness increase is from 1 to 2.5 while the cutting speed is reduced from about 5 to 1.

The cutting speed for any value of tool life for various values of hardness can be determined from Fig. 3.

Cutting Speed

The cutting speed greatly influences the quality of the machined surface, even independently of the size of cut, tool shape, and other cutting conditions. In cutting a steel at low speed, the finish is usually poor. Under these conditions a high rake should be used, a light feed, and a cutting fluid consisting of an oil containing sulfur or chlorine. As the cutting speed is increased, the finish becomes better. For each structure a cutting speed is obtained at which the built-up edge disappears, the cutting edge actually scrapes the work surface and produces a keen cut or burnished surface. The speed at which this superior finish is obtained varies not only with the type of steel cut, but with the structure of the steel. This speed is lowest for the hardest metals, and highest for the softest metals.

Under normal cutting, such as when high speed steels are cutting at moderate speeds, cooling is believed to be the primary function of the cutting fluid so that aqueous solutions or emulsions are more desirable. These cutting fluids should be applied at relatively low temperature, such as from 80° to 110° Fahr., in large quantities and at high velocity.

**Machinability — Its Vital Role in War Production by O. W. Boston, Univ. of Michigan in SCREW MACHINE ENGINEERING, June 1943, pp. 30-40.

THE S.A.E. NUMBERING SYSTEM

Most S.A.E. steels are standardized by numbers. The index system which has been devised facilitates ready identification of their type and composition.

In this system, with simple alloy steels, the first digit denotes the class of steel, i.e.,

'1'—denotes Carbon Steel
'2'— " Nickel Steel
'3'— " Nickel-Chrome Steel
etc.

The second digit denotes the percentage of the predominating alloy material or element.

The last two or three digits indicate the average carbon content in hundredths of 1%. Accordingly, 2340 Steel, for example, is a nickel steel containing approximately 3% nickel and .40% carbon. The basic numerals for the various types of S.A.E. Steels are shown below. In a few instances only, it has been necessary to depart from this system, for instance, when dealing with corrosion and heat resisting alloys.

*Type of Steel**	*Numerals (and Digits)**
Carbon Steels	1xxx
Plain Carbon	10xx
Free Cutting, (Screw Stock)	11xx
Manganese Steels	13xx
Nickel Steels	2xxx
3.50 per cent Nickel	23xx
5.00 per cent Nickel	25xx
Nickel Chromium Steels	3xxx
1.25 per cent Nickel, 0.60 per cent Chromium	31xx
1.75 per cent Nickel, 1.00 per cent Chromium	32xx
3.50 per cent Nickel, 1.50 per cent Chromium	33xx
Corrosion and Heat Resisting Steels	30xxx
Molybdenum Steels	4xxx
Carbon Molybdenum	40xx
Chromium Molybdenum	41xx
Chromium Nickel Molybdenum	43xx
Nickel Molybdenum; 1.75 per cent Nickel	46xx
Nickel Molybdenum; 3.50 per cent Nickel	48xx
Chromium Steels	5xxx
Low Chromium	51xx
Medium Chromium	52xxx
Corrosion and Heat Resisting	51xxx
Chromium Vanadium Steels	6xxx
1 per cent Chromium	61xx
National Emergency Steels	8xxx
Silicon Manganese Steels	9xxx
2 per cent Silicon	92xx

*Ref.: 1943 S.A.E. Handbook, P. 302.

LABORATORY RESEARCH PROCEDURE

Laboratory research procedure in the study of sulfurized cutting oils was planned with long range objectives. It was especially fortuitous that the research chemists as a whole subconsciously anticipated war-time priorities on certain of the base materials. It simplified materially the production of the sulfurized cutting oils now in such great demand by the war industries. This research procedure was planned as follows:

1. *Study of Existing Cutting Oils*
   (a) Make-up and components.
   (b) Cutting ability on standard machine tools
2. *Study of Base Materials*
   (a) Dependability of source
   (b) Location of source
   (c) Use in existing cutting oils
   (d) Patent coverage
   (e) Behavior in service, as to
      1. Odor
      2. Sludging
      3. Separation (stability in storage)
      4. Discoloration of work or tool
3. *Methods of Preparing Suitable Cutting Oils*
   (a) Effect of chemical composition
   (b) Effect of pressure
   (c) Effect of temperature
   (d) Effect of time

FIELD RESEARCH PROCEDURE

Concurrent with laboratory research the cutting effects of various types of experimental cutting oils was observed on thread cutting machines, turret lathes, and other heavy duty tools.

Service Performance

In conjunction with field research, it was concluded that cutting oil performance in actual service should be studied from the several angles in which the tool operator is most interested, i.e.:

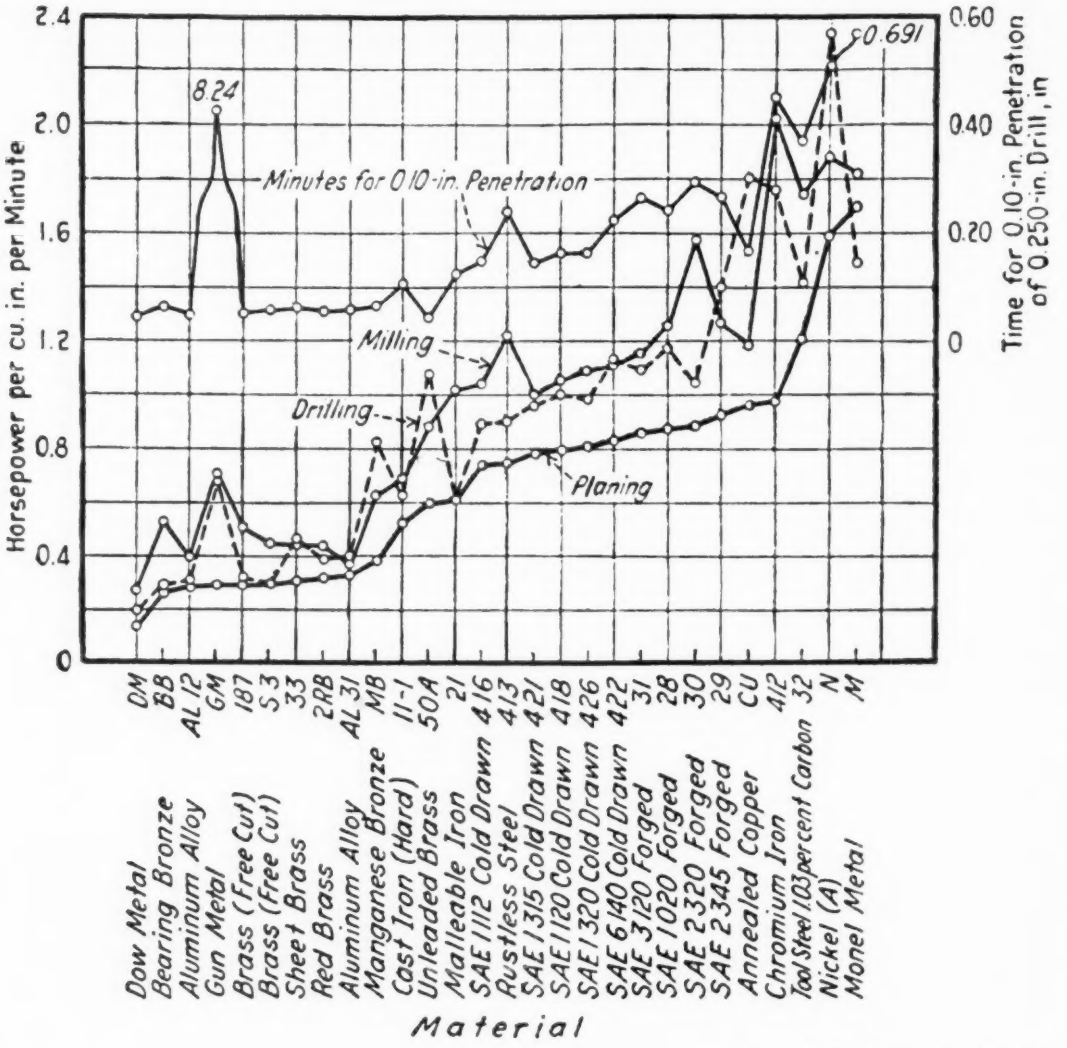
1. Cutting ability
   (a) Tool life
   (b) Surface finish
2. Protection against rusting
3. Ability to resist smoking or fogging

Cutting Ability

In the final analysis, a cutting oil is measured by its cutting ability, presuming that it meets the other requirements as to non-sludging, freedom from objectionable odors and freedom from sulfur precipitation.

Proof testing for cutting ability was studied in the laboratory on thread cutting machines, observing and recording.

(a) Noise or squealing
(b) The degree of smoothness of the thread
(c) Temperature rise during cutting.



From Screw Machine Engineering—June, 1943

FIG. 2—NET VALUES OF HORSEPOWER PER CUBIC INCH OF METAL CUT PER MINUTE FOR A VARIETY OF METALS AS DETERMINED FOR DRILLING, MILLING, AND PLANING. The drill used was ¾ in. dia., had a 30-deg. helix, and was operated at 153 r.p.m. and 0.012 i.p.r. feed. The planing tool was of the end-cutting type ½ in. wide, having 15-deg. back rake, no side rake, and operated at a speed of 20 f.p.m. when taking a depth of cut per stroke of 0.010 in. The milling cutter was of the end-cutting type 0.25 in. wide, 3.5 in. dia., having 15-deg. back rake, no side rake when taking a depth of cut of 0.125 in., and a feed of 0.010 in. per tooth. The penetrator drill indicating machinability was ¼ in. dia., had a helix of 24 deg., and operated under a feed load of 94 lb. at 500 r.p.m.

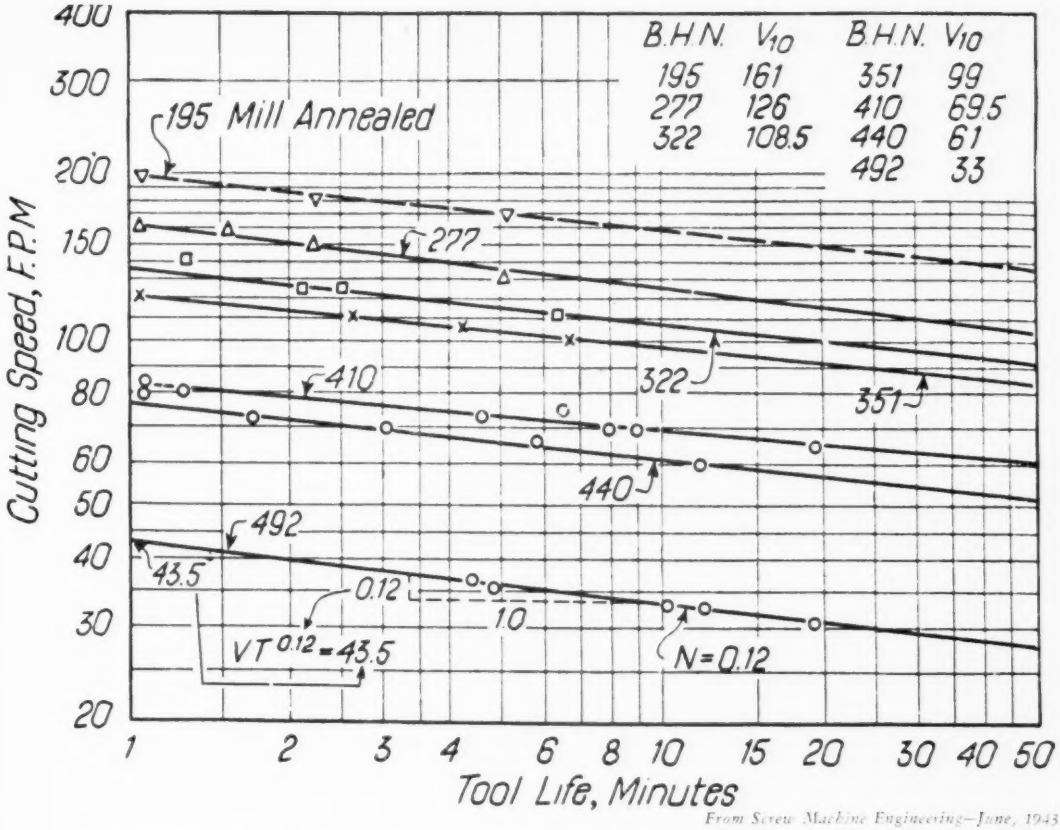
Tool Life

The life of a metal cutting tool is measured by the number of pieces which can be cut, threaded or shaped before the cutting edge of the tool becomes sufficiently dull to require redressing. Obviously a cutting oil which will extend the tool life is most desirable.

Surface Finish a Measure of Cutting Ability

The surface finish is affected by the rake angle of the cutting tool, the depth of cut, the friction between the chip and tool, and the plastic or elastic properties of the material being cut, along with the cutting quality of the oil.

Pipe thread cutting afforded an excellent means of observing the lubricating and cooling properties of an oil with respect to the operating conditions outlined above. In turn, it afforded a means of evaluating any oil under test according to —



From Screw Machine Engineering—June, 1943

Fig. 3—A log chart showing the relationship between cutting speed and tool life in minutes for a feed of 0.0127 inches and depth of cut of 0.050, when turning S.A.E. 4340 Steel, heat treated to give various degrees of hardness. (The cutting tools had 8° back rake, 14° side rake, 15° side cutting edge angle, and 3/64" nose radius. They were of 18-4-2 steel.)

tool life	smoking
surface finish	odor
chip sticking	discoloration

Protection Against Rusting

The ability of a cutting oil to prevent rusting of a freshly machined steel surface is influenced by the wetting properties of the oil. A cutting oil of good wettability and oiliness is to be preferred to one which tends to creep from the metal surface to leave bare spots exposed to oxygen and moisture in the air.

Smoking and Fogging

A good cutting oil must be of sufficiently high flash and fire test to resist smoking and fogging when exposed to the increased surface temperatures developed during cutting.

Smoothness of Cut Surfaces as Tested by the Lead Abrasion Method

The smoothness of the cut surface is generally agreed upon as being an excellent criterion as to the suitability of a cutting oil. The "lead abrasion" method afforded an interesting means of comparing cutting oils quantitatively as to their influence on surface finish and effective tool life. Some earlier investigators had studied methods of measuring

(1) power used in cutting
(2) cutting temperature
(3) tool life tests
(4) current shop practice

The "lead abrasion" method however has proved to be more dependable. It involves study of the surface finish when a pencil lead is passed over a certain linear distance of the surface, the results being recorded in terms of inches of wear of the lead. Any restriction in free flow of the chips across and away from the rake of the tool causes erratic results in the lead abrasion readings and usually produces inferior surfaces.

Reproducibility is highly important in connection with such a test. A heavy duty turret lathe was used to good advantage in developing the method of procedure by making a cut on the end of a piece of lap-welded or seamless steel pipe. The roughness of the cut surface is measured in terms of

THREAD CUTTING PERFORMANCE

Evaluated on a Typical Thread Cutting Machine

Chuck Speed R.P.M. F.P.M. PRODUCT	25 15	35 22	45 28	58 36	78 48	66 106
Cutting Oil B (High quality sulfurized oil)	Good	Good	Good	Good	Good; torn slightly	Fair; torn slightly
Cutting Oil X (Ordinary oil)	Fair	Poor; threads torn badly	Poor; threads torn badly	Poor; threads torn badly	Poor; threads torn badly	Poor; threads torn badly; chattered
Cutting Oil Y (Ordinary oil)	Poor; threads torn badly	Fair; threads torn	Fair; threads torn	Fair; threads torn	Fair; threads torn	Poor; threads torn badly

inches of lead worn off when the pencil-lead abrasion apparatus is passed over a definite linear distance of the surface. The lead abrasion apparatus provides for keeping pressure on the pencil-lead essentially constant regardless of the wear on the lead. The force necessary to exert pressure on the lead point is developed through an air cylinder and piston.

REACTION OF SULFUR WITH MINERAL OILS

Experience with sulfurizing mineral oils has indicated that when sulfur and mineral oils are in intimate contact, there is a gradual change in their behavior as the temperatures are increased. Thus at low temperatures, it is mainly a question of the solubility of sulfur in the oil, while at more elevated temperatures, particularly when the ingredients are maintained at these temperatures for a considerable period, it is a question of interaction accompanied by some solution of sulfur in the oil. During the early development of sulfur cutting oils, extensive investigational work was carried out involving:

(1) study of methods of incorporating sulfur in light viscosity mineral oils
(2) investigation of reasons for sludge separation during storage
(3) the most effectual processing temperature
(4) the potential benefits of air blowing to reduce the corrosive tendency of the finished oil, by removal of volatile acidic by-products
(5) the benefits (if any) which might accompany re-distillation

Factors Investigated

During the course of the research the following factors were considered as important:

1. The performance of sulfurized oils vs. sulfurized oil bases blended with straight mineral oil.
2. The suitability of sulfurized fatty oil vs. sulfurized fatty oil base blended with sulfurized and unsulfurized mineral oil. The fatty oils included prime lard oil, cottonseed oil, No. 1 lard, rapeseed, whale and castor oils.
3. The effect of viscosity, by using light vs. heavy mineral oils.
4. The merits of various deodorants in masking odor and preventing sedimentation.

CONCLUSION

It is the function of the cutting oil to interpose and maintain a suitable film between the working face of the cutting tool and work; also on the clearance side. The basic principle of lubrication holds true in that conversion of solid friction to fluid friction is absolutely necessary to prevent premature wear-out of metal parts moving with respect to one another.

Sulfur facilitates the obtaining of this objective. But sulfur cannot be added at random to a petroleum oil. Exhaustive research has proved that the manner of compounding and the nature of the materials to be compounded are the salient factors.

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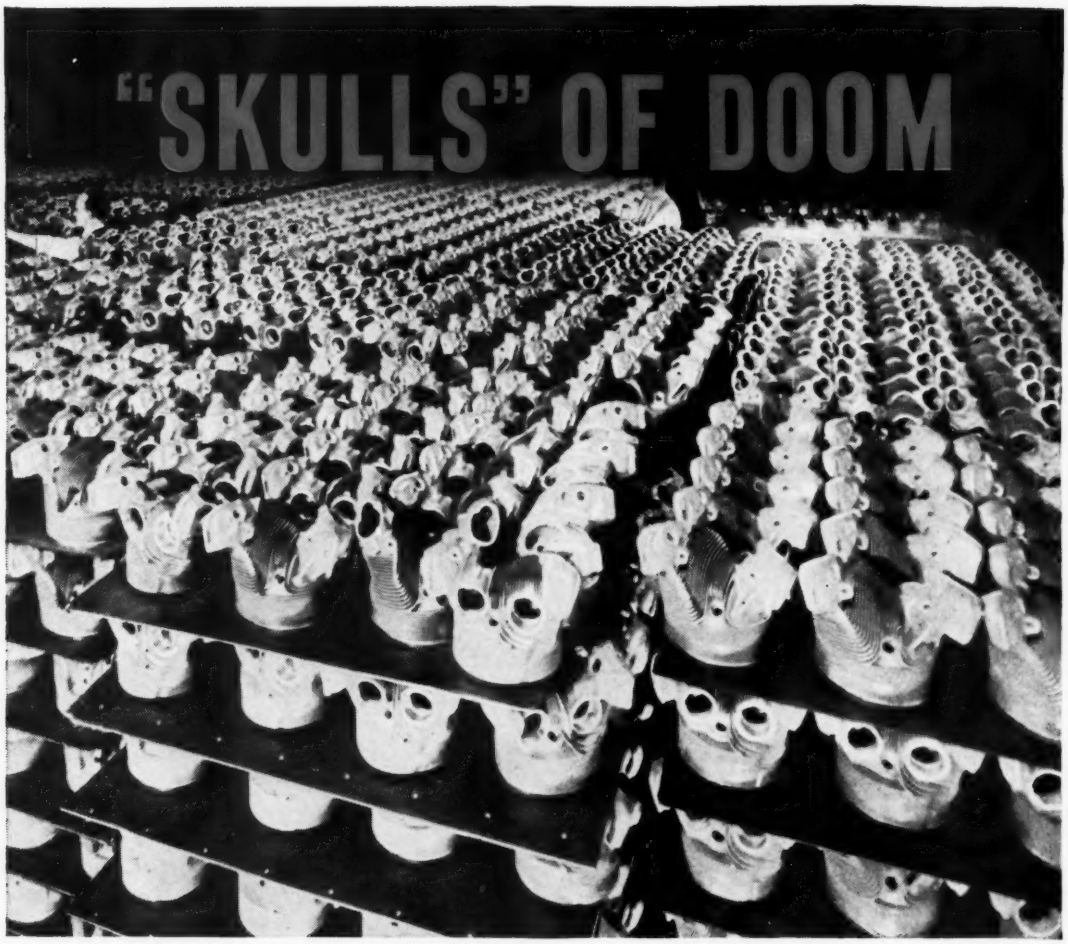

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